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Stöhr, Frederik; Michael-Lindhard, Jonas; Simons, Hugh; Hübner, Jörg; Jensen, Flemming; Hansen, Ole; Snigirev, A.; Poulsen, Henning Friis

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Manufacturing and Characterization of Silicon Compound Refractive Lenses for Focussing of Hard X-Rays

F. Stöhr[1,2], J.M. Lindhard[2], H. Simons[1,3], J. Hübner[2], F. Jensen[2], O. Hansen[4], A. Snigirev[3] and H.F. Poulsen[1]*

[1]*Department of Physics, Technical University of Denmark, Denmark*
[2]*DTU Danchip, Technical University of Denmark, Denmark*
[3]*ID06, European Synchrotron Radiation Facility, France*
[4]*Department of Micro- and Nanotechnology, Technical University of Denmark, Denmark*

Optical components are integral parts of hard (E > 10 keV) x-ray imaging instruments. Lenses of different designs exist to collimate and focus the incident x-ray beam onto specimens and enable imaging with an increase in sensitivity and resolution. The development of compound refractive x-ray lenses (CRLs) made of low-Z materials [1] has enabled the focussing of high energy x-rays to a beam waist of 50 nm and a gain in flux density above 10^4 [2]. The authors have started an initiative to build upon these achievements and employ state-of-the-art silicon planar technology at DTU Danchip, the cleanroom facility of the Technical University of Denmark, to manufacture parabolic CRLs by UV lithography and deep reactive ion etching and aim to generate hard x-ray beam waists below 40 nm, thereby approaching the diffraction limit. The characterization of the overall 3D shape of each etched parabolic cylinder comprising a whole CRL requires special attention, since a deviation from the ideal parabolic profile deteriorates its performance. A lateral widening of ~1 um related to the designed shape determined by applying scanning electron microscopy is a consequence of the lithography step (Figure 1a). Confocal microscopy allows profiling of cross-sections of the etched features and revealed an additional widening of the shape of ~1 um along the 50 um etch-depth, corresponding to a steepness of ~91.2° of the etch (Figure 1b). Thermal oxidation with subsequent etching of the grown oxide layer with buffered hydrofluoric acid reduced the surface roughness of the etched lenses from 90 nm to below 20 nm. Future studies will aim to optimize the process steps, improve the design and develop techniques for *ex-situ* characterization of silicon CRLs.

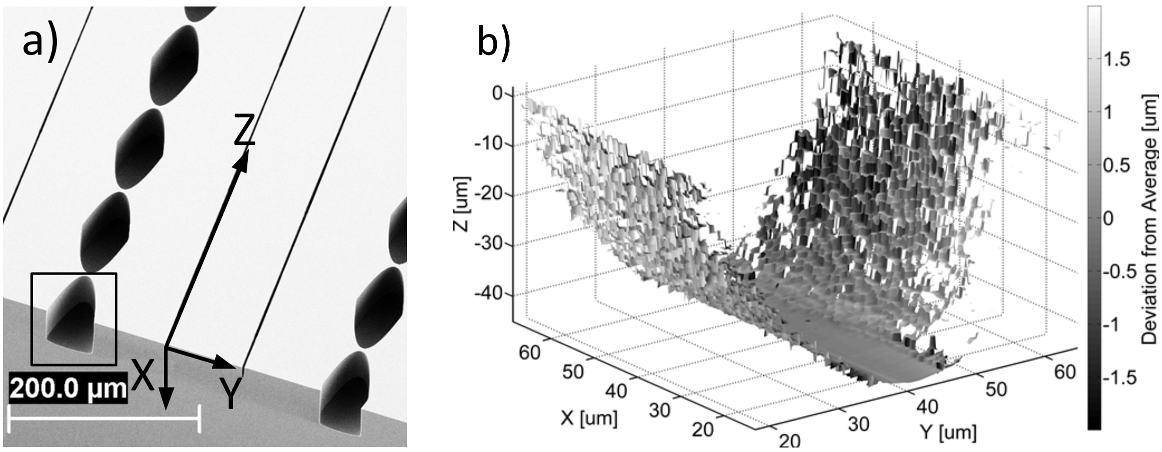

Figure 1: a) A scanning electron micrograph of a section of a silicon parabolic CRL subsequent to the etch process cleaved along the Y-axis. Scanning the highlighted part by confocal microscopy revealed its 3D shape shown in b). Within an area of ±5 um around the apex, the profile is smooth. Although the rest of the profile appears as highly corrugated, which is due to the limits of the confocal microscope when dealing with steep slopes and weak backscattered light, these measurements allow the optimization of the etch step.

References

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* frsto@danchip.dtu.dk